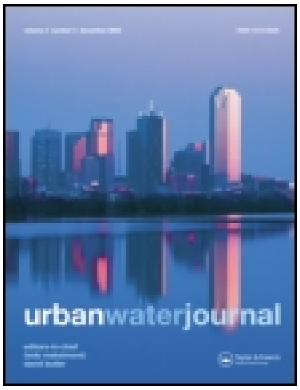


Urban Water Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/nurw20

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Published online: 15 Apr 2013.

To cite this article: S. Sandoval, A. Torres, M. Duarte & A. Velasco (2014) Assessment of rainfall influence over water quality effluent of an urban catchment: a data driven approach, Urban Water Journal, 11:2, 116-126, DOI: 10.1080/1573062X.2013.765492

To link to this article: http://dx.doi.org/10.1080/1573062X.2013.765492

*Urban Water Journal*, 2014
Vol. 11, No. 2, 116–126, http://dx.doi.org/10.1080/1573062X.2013.765492

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RESEARCH ARTICLE

# Assessment of rainfall influence over water quality effluent of an urban catchment: a data driven approach

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(*Received 25 February 2012; final version received 26 December 2012*)

Experience has shown the important influence of rainstorm water in the arrival of pollutants to receiving water bodies. This paper presents an identification of rain gauge stations and rainstorm variables with influence over water quality parameters such as Temperature, Conductivity, pH and COD, measured in the effluent of an urban catchment. Fourteen rainfall events registered by eight rain gauge stations within or in the proximity of the studied catchment (El Salitre Basin, Bogotá, Colombia) were analysed by the use of correlation tests and Kernel Classificatory methods. Some sensitive water quality parameters to rainfall (maximum rainfall height, mean of height, total height; during a rainstorm event) were identified (pH, temperature, conductivity and settleable solids). Correlations were significant mainly for two rain gauge stations in the proximity (about 5 km) of the effluent and two others near the eastern mountains of the city (zone with high slopes).

**Keywords:** data driven; precipitation; urban water pollution; correlation tests; classification methods



## 1. Introduction

Throughout the years, experience has shown an important influence of rainstorm water in the arrival of pollutant loads and concentrations to receipt water bodies (Warith *et al.* 1998). For several flow rate values, wastewater composition varies due to dilution phenomena caused by rainfall water (Warith *et al.* 1998). With this perspective, rainstorm events might represent a significant variability in water quality for receipt water bodies with important anthropic influences.

Since the 1990s, studies about variability of water quality effluent of urban catchments have been performed (see, for example, Jacobsen *et al.* 1996, Gnecco *et al.* 2005). However, most of them did not describe in detail the influence of rainfall or omitted a considerable number of water quality parameters, representative enough of physical, chemical and bacteriologic variability, typically presented in urban rejections (Rosenzweig *et al.* 2008).

Studies like Lee *et al.* (2002) showed a relation between the total runoff volumes of rainstorm events and concentrations of urban constituents present in runoff like Total Suspended Solids (TSS). These experiences can be described as approaches focused on event mean concentrations (EMC) of the constituents during the event. It must be pointed out that this type of analysis may not include other characteristics of rainfall and water quality parameters during a specific rainfall event (e.g. rainfall maximum heights, maximum concentration, maximum concentration's variation, rainfall event's duration).

Studies have shown the relevance of rainfall dynamics over the transport of pollutants in urban catchments (Rosenzweig *et al.* 2008), but most of these do not inquire into the spatial relationship of rainfall with pollutants' concentrations and loads (Lee *et al.* 2002). Studies like Tiefenthaler and Schiff (2003) and Gnecco *et al.*, (2005) showed influences between rainfall event characteristics (particularly total heights, intensities and durations) over pollutant concentrations (specifically TSS, metals, and organic compounds) in a test environment. This fact makes results described above hardly generalizable to large and non homogeneous urban catchments. Measurements of water quality parameters inside the catchment could be implemented with the purpose of taking into account their variability due to the interaction of the runoff with the urban surfaces (like roads or roofs: see, for example, Tiefenthaler and Schiff 2003, Gnecco *et al.* 2005). However, the purpose of this research is to figure out these interactions as an integrated phenomenon, which is observable in the total behavior of the effluent, in terms of water quality. These approaches can bring up the

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possibility of studying the interaction between pollutant concentrations and the travel of the flow of water through the sewer system.

In Colombia, the relation between rainfall and water quality draining from an urban catchment have been addressed under a modeling approach (DíazGranados and Camacho 2003, Estupiñán *et al.* 2009). Although these kinds of physically-based numerical models can become supporting tools in drainage systems management, their main objective was not to inquire in the relationship between rainfall characteristics (intensity, rainfall height, spatial distribution, antecedent dry weather period) and the water quality parameters of the effluent.

The purpose of this research was to identify influences of pluvial characteristics over variables related to water quality parameters by the use of statistical tools and mathematical classification methods. In order to accomplish this objective, several rainfall events registered over a study zone (El Salitre basin, Bogotá, Colombia) were analyzed.

## 2. Materials and methods

### *2.1. Experimental site*

The Salitre river basin is included in the median basin of the Bogotá river, which merges downstream of the Chicú river. It is found in the northern part of the hydrologic system of Bogotá and contains: (i) Torca channel; (ii) Conejera wetland; (iii) Juan Amarillo or Salitre river, which receives the water from Córdoba wetland and Contador, Córdoba, Callejas and Molinos' channels at the north side and the water of Río Negro river, Virrey channel and Salitre channel (this last one receives water from the Arzobispo stream) on the south side; (iv) Jaboque wetland. The Salitre basin has 22 sanitary sub-basins which sum up to 13,251.484 hectares. Nowadays, the north-east and north-west part of the catchment works with separate sewer systems and the south part (the older one) work mainly as combined. Wastewater of the 22 sub-basins discharges to the treatment facility, whose effluent empties into Bogotá River (adapted from Rada and Torres 2011).

### *2.2. Data collection and processing*

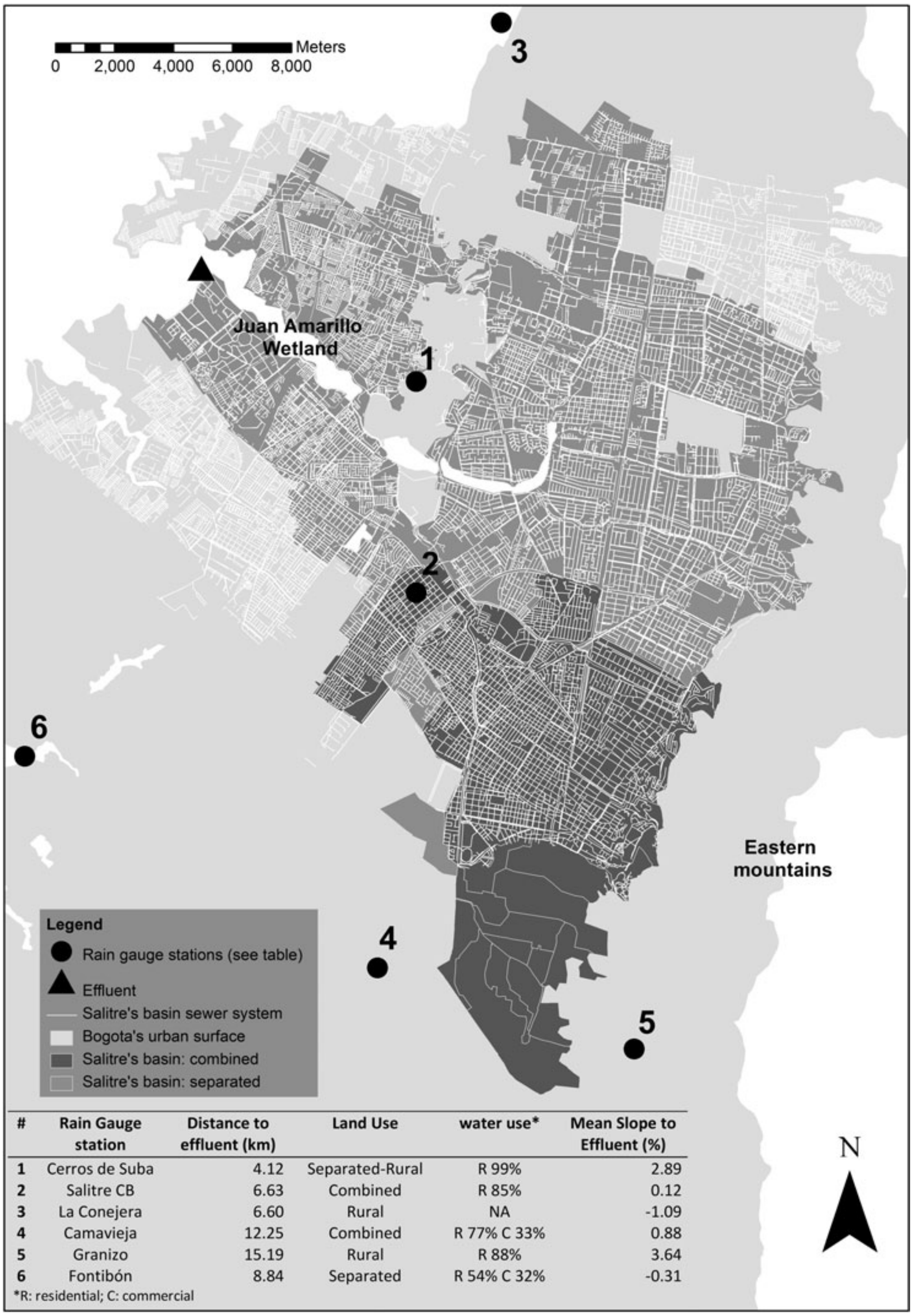
Between 15 January and 4 February 2009, Bogotás Water and Sewage Company (EAAB) led a monitoring campaign on the wastewater network of the Salitre basin. For this monitoring campaign seven experimental points were established, in which flow rate and water quality measurements (Temperature, Conductivity, pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) and Settleable Solids (SS)) were performed. The 7th experimental point is situated in the incoming Salitre channel, 500 m upstream of the pumping station. The analysis of the present paper was developed for this specific point due to its representativeness as the effluent of the whole catchment (inlet channel to WWTP). During this campaign, for the selected point, flow rate, Temperature, Conductivity, pH and SS were measured *in situ*, with a temporal resolution of two hours. Furthermore, BOD, COD, TSS and VSS were measured with a temporal resolution of four hours, by the use of grab sample's technique and laboratory analysis were undertaken following the Standard Methods for Examination of Water and Wastewater's recommendations (APHA 1995) (Electrometric 5210-B, Volumetric 5220-B, Gravimetric 2540-D and Gravimetric 2540-D, respectively). Rainfall information was registered by eight rain gauge stations[1] within or in proximity of the studied catchment (adapted from Rada and Torres 2011).

Figure 1 shows a map with the location of the eight EAAB rain gauge stations used for rainfall measurements in the catchment. El Salitre's channel location is also shown.

As mentioned, measured variables had different temporal resolutions – (i) COD, BOD and TSS: four hours; (ii) volumes, flow rates, pH, conductivity, temperature: two hours; (iii) rainfall heights: one hour. In order to achieve an appropriate uniformity of the temporal series (set to four hours for all analyzed variables), a temporal aggregation of rainfall, volumes and loads to four hours was performed.[2] For flow rates, pH, conductivity and temperature, punctual data registered each four hours without aggregation was used. This resolution was selected with the purpose of avoiding additional uncertainties in subsequent data analysis coming from interpolated values, used to complete the data set for time instants without measurements, whenever a finer resolution was selected.

### *2.3. Data analysis*

In order to define a rainfall event, identifying null precipitation periods, the beginning of the event, the end of the event and the duration of null precipitation period that separates two independent rainfall events becomes necessary. In general terms, two rainfall events can be considered mutually independent if the resulting effects of the first event have ceased before the beginning of the second one (adapted from Chocat 1997). Measured data of any parameter related to water quality or quantity in the effluent will be considered part of a rainfall event whenever at the same time-step any rainfall height is registered in at least one of the eight rain gauge stations within or in proximities of the studied catchment (labeled as "YES" in the "Training Data" column, Table 1). Otherwise, just in the case that a sufficiently long time (exceeding the concentration time of the basin, assumed for this study to be about 11–17 h; Uniandes-EAAB 2007) has passed without rainfall registrations in any of the rain gauge stations, complete cessation of rainstorm event can be assumed (labeled as "NO" in the "Training Data" column, Table 1). For remaining time-steps, uncertainty exists about their belonging or not to a rainfall event due to the simultaneous occurrence of the following conditions for a given time-step (filled with a "?" symbol in Table 1, "Training Data" column): (i) zero rainfall height was registered in all the rainfall gauge stations; (ii) the time that has passed since the last registered non-zero rainfall height is less than 12 h. For above situations, classification methods with an appropriate predictability can be implemented. The importance of identifying, with some confidence, the time windows in which rainfall events




| # | Rain Gauge station | Distance to effluent (km) | Land Use | water use* | Mean Slope to Effluent (%) |
|---|---|---|---|---|---|
| 1 | Cerros de Suba | 4.12 | Separated-Rural | R 99% | 2.89 |
| 2 | Salitre CB | 6.63 | Combined | R 85% | 0.12 |
| 3 | La Conejera | 6.60 | Rural | NA | -1.09 |
| 4 | Camavieja | 12.25 | Combined | R 77% C 33% | 0.88 |
| 5 | Granizo | 15.19 | Rural | R 88% | 3.64 |
| 6 | Fontibón | 8.84 | Separated | R 54% C 32% | -0.31 |

*R: residential; C: commercial

Figure 1. El Saltire's Basin. Bogotá, Colombia.

Table 1. Rainfall and water quality registers from 15 January, 2:00 pm to 18 January, 2:00 pm (2009), including a priori detection of time-steps' membership to rainfall events.

| | Water Quality Parameters | | | | | | | | | Rainfall (mm) | | | | | | | | Training data | Model prediction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time (h) | Q ($m^3/s$) | TSS (mg/l) | BOD (mg/l) | VSS (mg/l) | COD (mg/l) | pH | T (°C) | K (S/m) | SS (mg/l) | La Conejera | Camavieja | Cerros de Suba | Salitre CB | Granizo | San Diego | Fontibón | La Caro | IS RAIN-FALL EVENT? | IS RAIN-FALL EVENT? |
| 4 | 4.33 | 122 | 191 | 90 | 471 | 7.26 | 19.2 | 963 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ? | (1) |
| 8 | 3.83 | 170 | 261 | 113 | 560 | 7.35 | 18.3 | 1005 | 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ? | (1) |
| 12 | 4.32 | 90 | 190 | 28 | 449 | 7.19 | 18.4 | 1104 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NO | NO |
| 16 | 4.33 | 572 | 267 | 395 | 571 | 7.31 | 17.9 | 1129 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NO | NO |
| 20 | 4.18 | 96 | 181 | 58 | 519 | 7.5 | 17.9 | 1042 | 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NO | NO |
| 24 | 3.80 | 164 | 552 | 108 | 2103 | 7.8 | 21.5 | 1211 | 5 | 0 | 0 | 0 | 0 | 0 | 1.6 | 0 | 0 | YES | YES |
| 28 | 4.16 | 276 | 159 | 196 | 435 | 7.4 | 20 | 1027 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ? | (1) |
| 32 | 4.12 | 122 | 166 | 66 | 539 | 7.37 | 18.7 | 988 | 4 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0.3 | YES | YES |
| 36 | 4.41 | 116 | 164 | 72 | 467 | 7.72 | 16.6 | 1234 | 1 | 0 | 0 | 0 | 0 | 0.7 | 0 | 0 | 0 | YES | YES |
| 40 | 4.30 | 550 | 324 | 390 | 406 | 8.03 | 18.7 | 1165 | 0.5 | 0.2 | 0.8 | 0 | 0 | 0.2 | 0 | 0.1 | 0 | YES | YES |
| 44 | 4.27 | 172 | 164 | 116 | 357 | 8.44 | 18 | 1105 | 0.5 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | YES | YES |
| 48 | 3.90 | 132 | 211 | 72 | 386 | 8.39 | 20.6 | 1275 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | YES | YES |
| 52 | 4.86 | 104 | 160 | 76 | 428 | 7.8 | 20 | 1104 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | YES | YES |
| 56 | 5.02 | 92 | 252 | 64 | 509 | 7.8 | 18.3 | 695 | 6 | 1.6 | 1.1 | 0.5 | 0 | 2.7 | 0 | 0.4 | 0.9 | YES | YES |
| 60 | 3.95 | 252 | 163 | 160 | 414 | 7.7 | 17.7 | 719 | 4 | 0 | 0 | 0.5 | 0.3 | 0 | 0 | 0 | 0 | YES | YES |
| 64 | 4.74 | 915 | 390 | 440 | 993 | 7.64 | 17.7 | 1127 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | YES | YES |
| 68 | 4.73 | 320 | 191 | 100 | 412 | 8.02 | 16.2 | 997 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ? | (1) |

(1): NO assessed by Kernel methods
(2): YES assessed by Kernel methods (for the complete measuring campaign) Q: flow, TSS: total suspended solids, BOD: biochemical oxygen demand, VSS: volatile suspended solids, COD: chemical oxygen demand, pH, T: temperature, K: conductivity, SS: settleable solids.